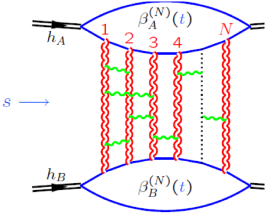
Soft and hard diffraction and photon exchange processes at the LHC

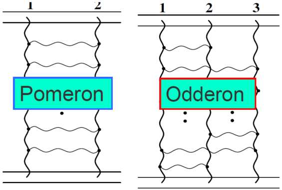
Christophe Royon
University of Kansas, Lawrence, USA
20th Zimanyi School, Budapest, Hungary

December 8 2020

- Soft diffraction: evidence for the odderon by comparing pp and $p\bar{p}$ data
- Hard diffraction at the LHC
- Photon exchange processes and beyond standard model physics

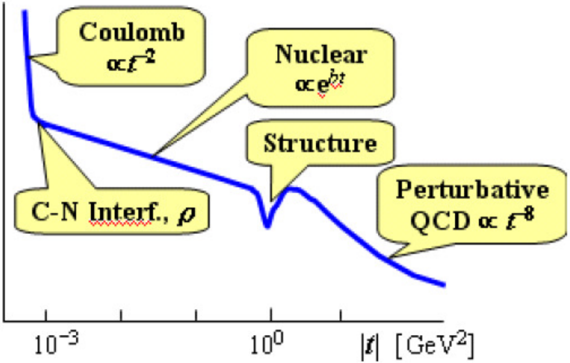
Soft diffraction at the LHC: What is the odderon?





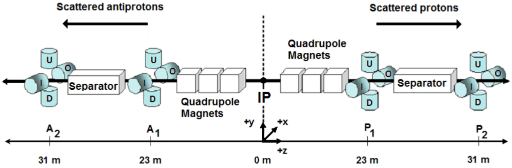
- Multi-gluon exchanges in hadron-hadron interactions in elastic *pp* interactions (Bartels-Kwiecinski-Praszalowicz)
- From B. Nicolescu: The Odderon is defined as a singularity in the complex plane, located at $J = 1$ when $t = 0$ and which contributes to the odd crossing amplitude
- Leads to contributions on 2, 3,... gluon exchanges in terms of QCD for the perturbative odderon
- Colorless C-odd 3-gluon state (odderon) predicts differences in elastic $d\sigma/dt$ for pp and $p\bar{p}$ interactions since it corresponds to different amplitudes/ interferences

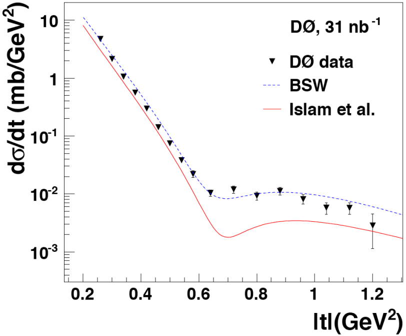
Measurement of elastic scattering at Tevatron and LHC



- Study of elastic $pp \rightarrow pp$ reaction: exchange of momentum between the two protons which remain intact
- Measure intact protons scattered close to the beam using roman pots installed both by D0 and TOTEM collaborations
- From counting the number of events as a function of $|t|$ (quadri-momentum transferred square at the proton vertex measured by tracking the protons), we get $d\sigma/dt$

D0 elastic $p\bar{p}$ $d\sigma/dt$ cross section measurements

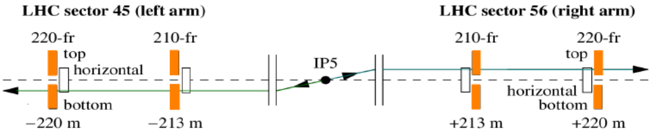


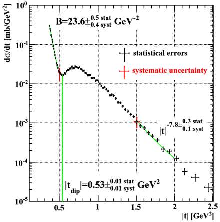


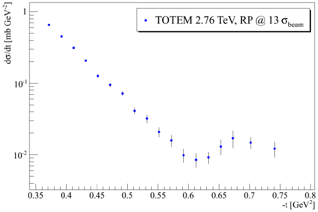
- D0 collected elastic $p\bar{p}$ data with intact p and $\bar{p}$ detected in the Forward Proton Detector with 31 nb^{-1} Phys. Rev. D 86 (2012) 012009
- Measurement on elastic $p\bar{p}$ $d\sigma/dt$ at 1.96 TeV for $0.26 < |t| < 1.2$ GeV^2

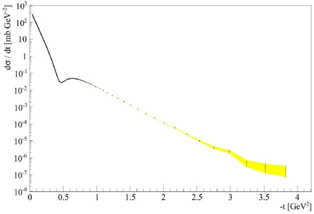
TOTEM elastic pp $d\sigma/dt$ cross section measurements

- Elastic pp $d\sigma/dt$ measurements: tag both intact protons in TOTEM roman pots 2.76, 7, 8 and 13 TeV
- Very precise measurements at 2.76, 7, 8 and 13 Tev: Eur. Phys. J. C 80 (2020) no.2, 91; EPL 95 (2011) no. 41004; Nucl. Phys. B 899 (2015) 527; Eur. Phys. J. C79 (2019) no.10, 861

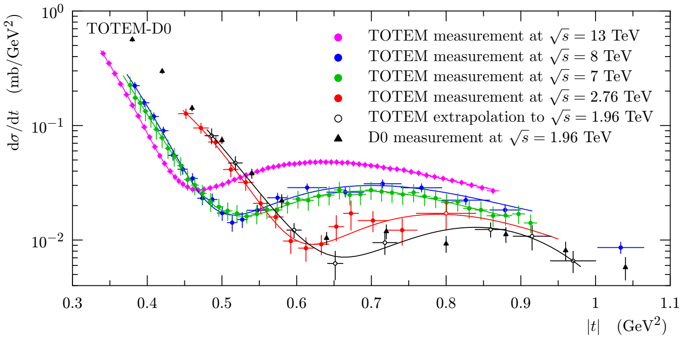






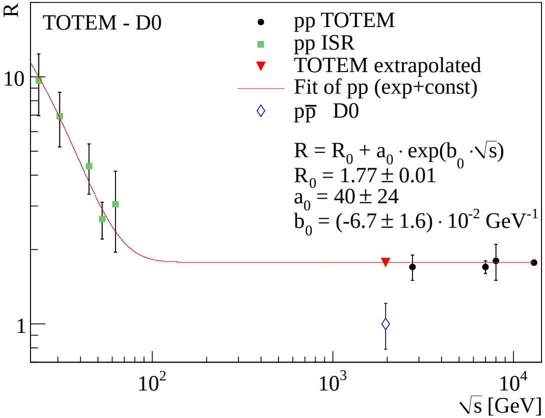


Strategy to compare pp and $p\bar{p}$ data sets



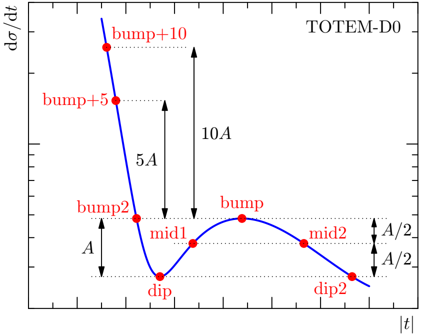
- In order to identify differences between pp and $p\bar{p}$ elastic $d\sigma/dt$ data, we need to compare TOTEM measurements at 2.76, 7, 8, 13 TeV and D0 measurements at 1.96 TeV
- All TOTEM $d\sigma/dt$ measurements show the same features, namely the presence of a dip and a bump in data, whereas D0 data do not show this feature

Bump over dip ratio



- Bump over dip ratio measured for pp interactions at ISR and LHC energies
- Bump over dip ratio in pp elastic collisions: decreasing as a function of $\sqrt{s}$ up to $\sim$ 100 GeV and flat above
- D0 $p\bar{p}$ shows a ratio of 1 given the fact that no bump/dip is observed in $p\bar{p}$ data within uncertainties: **more than 3σ difference between pp and $p\bar{p}$ elastic data** (assuming flat behavior above $\sqrt{s} = 100 GeV$)

Reference points of elastic $d\sigma/dt$



- Define 8 characteristic points of elastic *pp* $d\sigma/dt$ cross sections (dip, bump...) that are feature of elastic *pp* interactions

- Determine how the values of $|t|$ and $d\sigma/dt$ of characteristic points vary as a function of $\sqrt{s}$ in order to predict their values at 1.96 TeV
- We use data points closest to those characteristic points (avoiding model-dependent fits)
- Data bins are merged in case there are two adjacent dip or bump points of about equal value
- This gives a distribution of t and $d\sigma/dt$ values as a function of $\sqrt{s}$ for all characteristic points

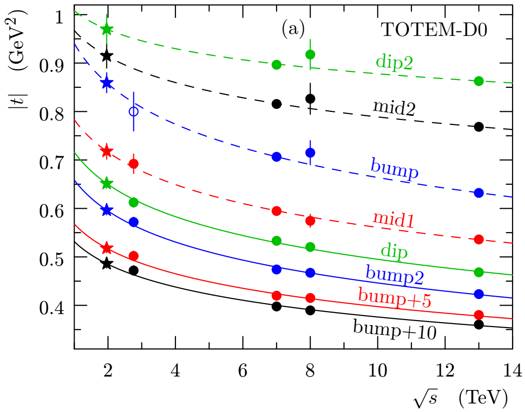
Fits of t and $d\sigma/dt$ values for reference points

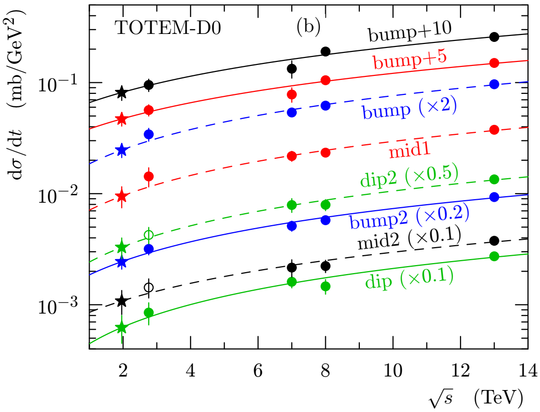
- Fit of all reference points using the following formulae:

$$\begin{aligned} |t| &= a \log(\sqrt{s}[\mathrm{TeV}]) + b \\ (d\sigma/dt) &= c\sqrt{s}\ [\mathrm{TeV}] + d \end{aligned}$$

- The same form is used for the 8 reference points (this is an assumption and works to describe all characteristic points): this simple form is chosen since we fit at most 4 points, corresponding to $\sqrt{s} = 1.96$, 7, 8 and 13 TeV
- We also tried alternate parametrizations leading to similar results
- Leads to very good χ^2 per dof, better than 1 for most of the fits
- By extrapolating the fits, leads to predictions on $|t|$ and $d\sigma/dt$ at 1.96 TeV for each characteristic point

Variation of t and $d\sigma/dt$ values for reference points

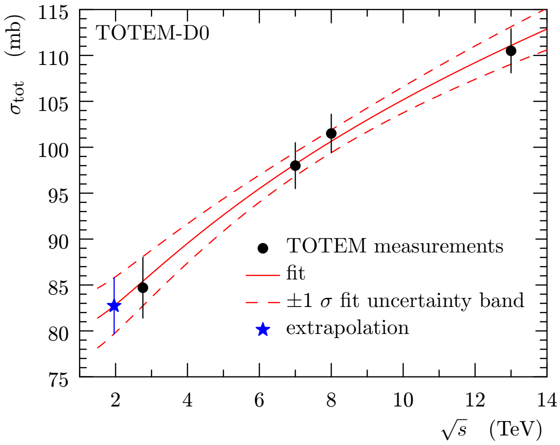




Fits of TOTEM extrapolated characteristic points at 1.96 TeV

- The last step is to predict the *pp* elastic cross sections at the same t values as measured by D0 in order to make a direct comparison
- Fit the reference points extrapolated to 1.96 TeV from TOTEM measurements using a double exponential fit ($\chi^2 = 0.63$ per dof): $h(t) = a_1 e^{-b_1|t|^2 - c_1|t|} + d_1 e^{-f_1|t|^3 - g_1|t|^2 - h_1|t|}$
  - This function is chosen for fitting purposes only
  - Low-t diffractive cone (1st function) and asymmetric structure of bump/dip (2nd function)
  - The two exponential terms cross around the dip, one rapidly falling and becoming negligible in the high t-range where the other term rises off the dip
- Systematic uncertainties evaluated from MC simulation in which the cross section values of the 8 characteristic points are varied within their Gaussian uncertainties. Only fits showing a bump and a dip within the uncertainties in the $|t|$-locations predicted by extrapolating TOTEM data, and also a slope and intercept at the first characteristic point ($|t| = 0.48$ GeV^2) are kept
- Such formula leads also to a good description of TOTEM data in the dip/bump region at 2.76, 7, 8 and 13 TeV

Relative normalization between D0 measurement and extrapolated TOTEM data: total pp cross section at 1.96 TeV



- Differences in normalization taken into account by adjusting TOTEM and D0 data sets to have the same cross sections at the optical point $d\sigma/dt(t=0)$ (NB: OP cross sections expected to be equal if there are only C-even exchanges)
- Predict the pp total cross section from extrapolated fit to TOTEM data (χ^2 =0.27)

$$\sigma_{tot} = a_2 \log^2 \sqrt{s}[\mathrm{TeV}] + b_2$$

- Leads to an estimate of pp total cross section at 1.96 TeV of σ_{tot} =82.7 ± 3.1 mb

Relative normalization between D0 measurement and extrapolated TOTEM data: Rescaling TOTEM data

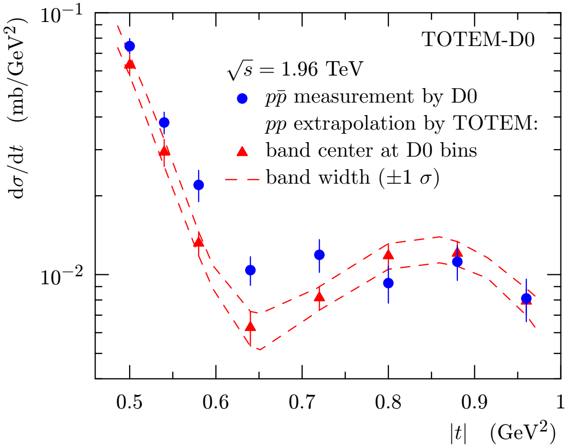
- Adjust 1.96 TeV $d\sigma/dt(t=0)$ from extrapolated TOTEM data to D0 measurement
- From TOTEM pp σ_{tot}, obtain $d\sigma/dt(t=0)$:

$$\sigma_{tot}^2 = \frac{16\pi(\hbar c)^2}{1+\rho^2}\left(\frac{d\sigma}{dt}\right)_{t=0}$$

- Assuming $\rho = 0.145$, the ratio of the imaginary and the real part of the elastic nuclear amplitude, as taken from COMPETE extrapolation
- This leads to a TOTEM $d\sigma/dt(t=0)$ at the OP of 357.1 ± 26.4 mb/GeV^2
- D0 measured the optical point of $d\sigma/dt$ at small t: 340.8 mb/GeV^2
- TOTEM data rescaled by 0.954 ± 0.074
- NB: We do not claim that we performed a measurement of $d\sigma/dt$ at the OP at $t=0$ (it would require additional measurements closer to $t=0$), but we use the two extrapolations simply in order to obtain a common and somewhat arbitrary normalization point

Predictions at $\sqrt{s} = 1.96$ TeV

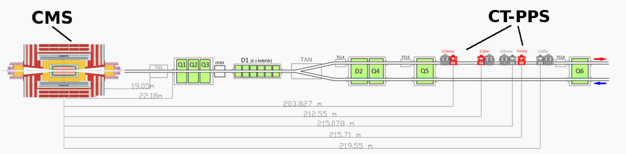
- Reference points at 1.96 TeV (extrapolating TOTEM data) and 1σ uncertainty band
- Comparison with D0 data

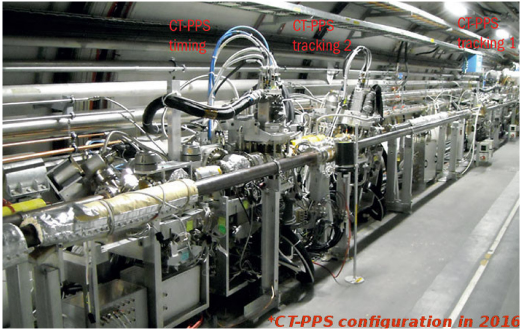


Comparison between D0 data and TOTEM extrapolated measurements

- Constrain the scaling between D0 and TOTEM to preserve the measured logarithmic slopes
- χ^2 test to examine the probability for the D0 and TOTEM differential elastic cross sections to agree. The test uses the difference of the integrated cross section in the examined $|t|$-range with its fully correlated uncertainty, and the experimental and extrapolated points with their covariance matrices
- **p-value of 0.00061 (6 dof), corresponding to a significance of 3.4σ $\rightarrow$ Evidence that the colorless C-odd three gluon state i.e. the odderon is needed to explain elastic scattering at high energies**
- Cross checked using the Kolmogorov Smirnov method
- **Combining with TOTEM ρ measurement will lead to 5.2 to 5.7 σ evidence for odderon**

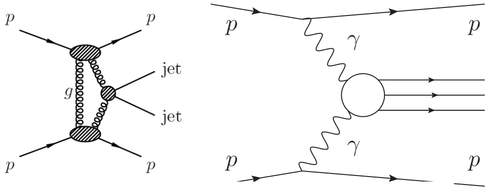
What is the CMS-TOTEM Precision Proton Spectrometer (CT-PPS)?

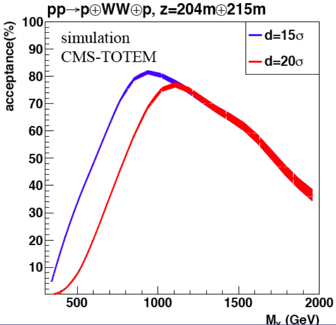




- Joint CMS and TOTEM project: https://cds.cern.ch/record/1753795
- LHC magnets bend scattered protons out of the beam envelope
- Detect scattered protons a few *mm* from the beam on both sides of CMS: 2016, first data taking ($\sim$ 15 fb^{-1})
- Similar detectors: ATLAS Forward Proton (AFP)

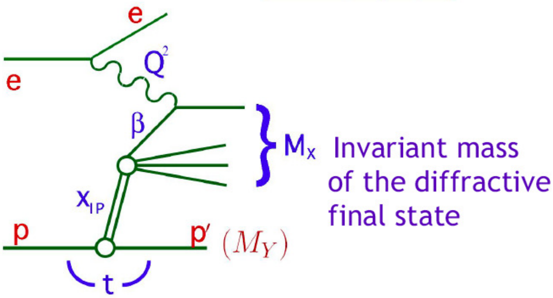
Detecting intact protons in ATLAS/CMS-TOTEM at the LHC





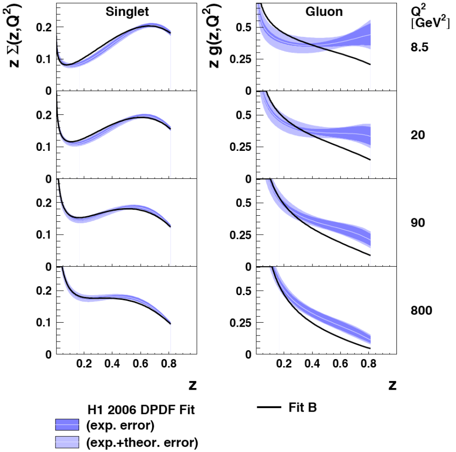
- Tag and measure protons at $\pm$210 m: AFP (ATLAS Forward Proton), CT-PPS (CMS TOTEM - Precision Proton Spectrometer)
- All diffractive cross sections computed using the Forward Physics Monte Carlo (FPMC)
- Complementarity between low and high mass diffraction (high and low cross sections): special runs at low luminosity (no pile up) and standard luminosity runs with pile up

Reminder: Diffraction at HERA



- Momentum fraction of the proton carried by the colourless object (pomeron): $x_p = \xi = \frac{Q^2+M_X^2}{Q^2+W^2}$
- Momentum fraction of the pomeron carried by the interacting parton if we assume the colourless object to be made of quarks and gluons: $\beta = \frac{Q^2}{Q^2+M_X^2} = \frac{x_{Bj}}{x_P}$
- 4-momentum squared transferred: $t = (p - p')^2$

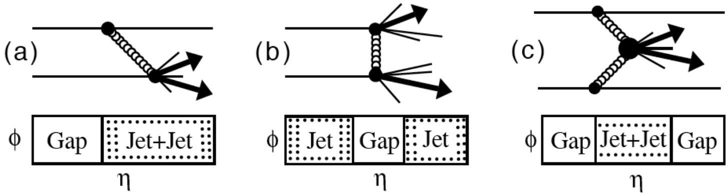
Reminder: Diffraction at HERA



- Measurement of the diffractive cross section using the rapidity gap selection
- Perform QCD fits using NLO Dokshitzer Gribov Lipatov Altarelli Parisi evolution equation
- At low β: evolution driven by $g \rightarrow q\bar{q}$, at high β, $q \rightarrow qg$ becomes important

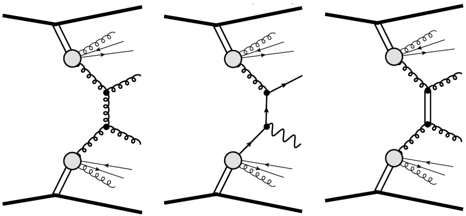
$$\frac{dF_2^D}{d\log Q^2} \sim \frac{\alpha_S}{2\pi}\left[P_{qg} \otimes g + P_{qq} \otimes \Sigma\right]$$

Diffraction at LHC: kinematical variables



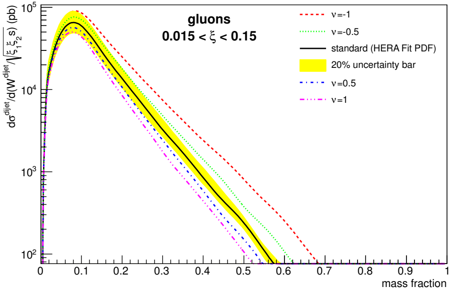
- t: 4-momentum transfer squared
- ξ_1, ξ_2: proton fractional momentum loss (momentum fraction of the proton carried by the pomeron)
- $\beta_{1,2} = x_{Bj,1,2}/\xi_{1,2}$: Bjorken-x of parton inside the pomeron
- $M^2 = s\xi_1\xi_2$: diffractive mass produced
- $\Delta y_{1,2} \sim \Delta\eta \sim \log 1/\xi_{1,2}$: rapidity gap

Hard diffraction at the LHC



- Understanding better the structure of the exchanged colorless object, the Pomeron
- Dijet production: dominated by gg exchanges
- γ+jet production: dominated by qg exchanges
- Jet gap jet in diffraction: Probe proton structure at high gluon densities

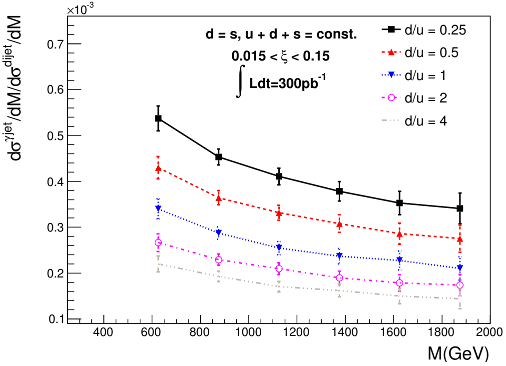
Inclusive diffraction at the LHC: sensitivity to gluon density



- Predict DPE dijet cross section at the LHC in PPS acceptance, jets with p_T >20 GeV, reconstructed at particle level using anti-k$_T$ algorithm

- Sensitivity to gluon density in Pomeron especially the gluon density on Pomeron at high β: multiply the gluon density by $(1-\beta)^\nu$ with $\nu = -1, ..., 1$
- Measurement possible with 10 pb^{-1}, allows to test if gluon density is similar between different accelerators (HERA and LHC) (universality of Pomeron model)
- Dijet mass fraction: dijet mass divided by total diffractive mass ($\sqrt{\xi_1 \xi_2 S}$)
- C. Marquet, C.R., M. Saimpert, Phys.Rev. D88 (2013) no.7, 074029

Inclusive diffraction at the LHC: sensitivity to quark densities

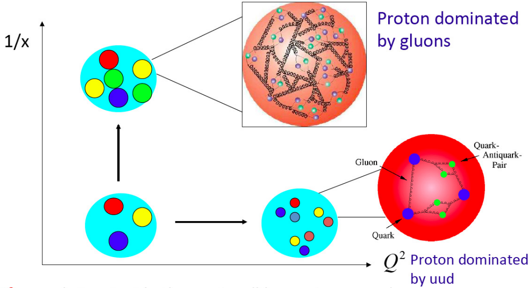


- Predict DPE γ+jet divided by dijet cross section at the LHC
- Sensitivity to universality of Pomeron model
- Sensitivity to quark density in Pomeron, and of assumption: $u = d = s = \bar{u} = \bar{d} = \bar{s}$ used in QCD fits at HERA

Looking for low x resummation effects effects

- Dokshitzer Gribov Lipatov Altarelli Parisi (DGLAP): Evolution in Q^2
- Balitski Fadin Kuraev Lipatov (BFKL): Evolution in x

Aim: Understanding the proton structure (quarks, gluons)

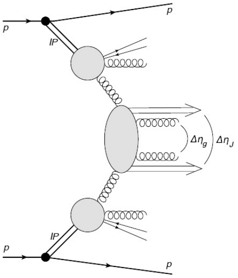


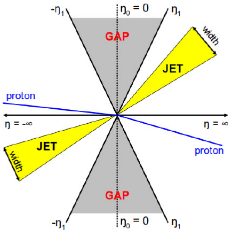
Q^2 : resolution inside the proton (like a microscope)

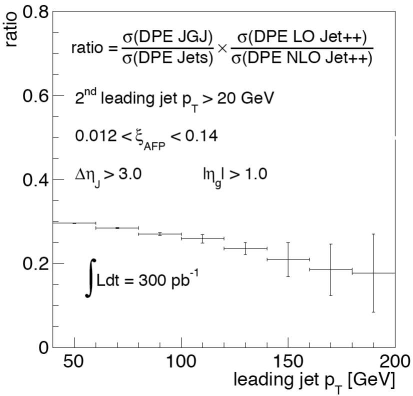
x :Proton momentum fraction carried away by the interacting quark

Jet gap jet events in diffraction

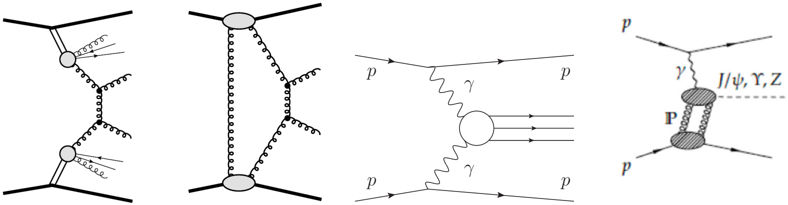
- Study BFKL dynamics using jet gap jet events in SD, DPE
- See: C. Marquet, C. Royon, M. Trzebinski, R. Zlebcik, Phys. Rev. D 87 (2013) 034010
- See talk by Cristian





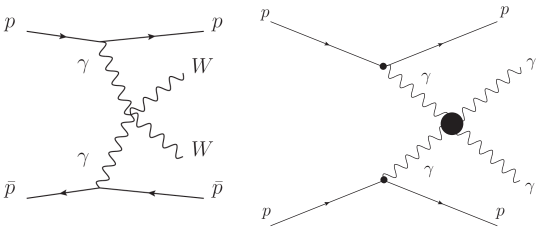


Exclusive diffraction



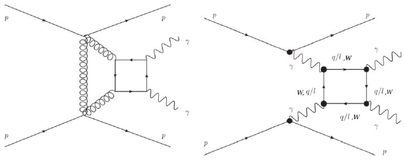
- Many exclusive channels can be studied: jets, χ_C, charmonium, J/Ψ....
- Possibility to reconstruct the properties of the object produced exclusively (via photon and gluon exchanges) from the tagged proton
- CMS/TOTEM has the possibility to discover/exclude glueballs at low masses: Check the $f_0(1500)$ or $f_0(1710)$ glueball candidates

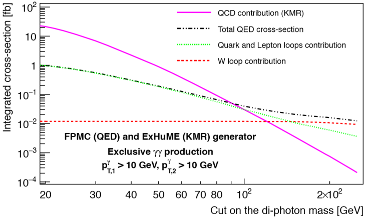
Search for $\gamma\gamma WW$, $\gamma\gamma\gamma\gamma$ quartic anomalous coupling



- Study of the process: $pp \rightarrow ppWW$, $pp \rightarrow ppZZ$, $pp \rightarrow pp\gamma\gamma$
- Standard Model: $\sigma_{WW} = 95.6$ fb, $\sigma_{WW}(W = M_X > 1 TeV) = 5.9$ fb
- Process sensitive to anomalous couplings: $\gamma\gamma WW$, $\gamma\gamma ZZ$, $\gamma\gamma\gamma\gamma$; motivated by studying in detail the mechanism of electroweak symmetry breaking, predicted by extradim. models
- Rich $\gamma\gamma$ physics at LHC: see papers by C. Baldenegro, S. Fichet, M. Saimpert, G. Von Gersdorff, E. Chapon, O. Kepka, CR... Phys.Rev. D89 (2014) 114004 ; JHEP 1502 (2015) 165; Phys. Rev. Lett. 116 (2016) no 23, 231801; JHEP 1706 (2017) 142; JHEP 1806 (2018) 131

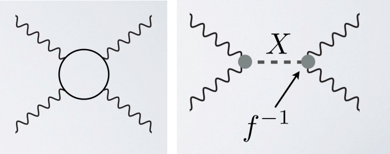
$\gamma\gamma$ exclusive production: SM contribution





- QCD production dominates at low $m_{\gamma\gamma}$, QED at high $m_{\gamma\gamma}$
- Important to consider W loops at high $m_{\gamma\gamma}$
- At high masses ($>$ 200 GeV), the photon induced processes are dominant
- **Conclusion: Two photons and two tagged protons means photon-induced process**

Motivations to look for quartic $\gamma\gamma$ anomalous couplings

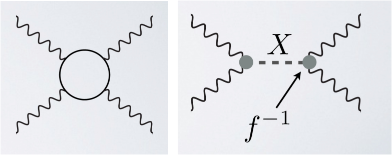


- Two effective operators at low energies

$$\mathcal{L}_{4\gamma} = \zeta_1^{\gamma} F_{\mu\nu} F^{\mu\nu} F_{\rho\sigma} F^{\rho\sigma} + \zeta_2^{\gamma} F_{\mu\nu} F^{\nu\rho} F_{\rho\lambda} F^{\lambda\mu}$$

- $\gamma\gamma\gamma\gamma$ couplings can be modified in a model independent way by loops of heavy charged particles $\zeta_1 = \alpha_{em}^2 Q^4 m^{-4} N c_{1,s}$ where the coupling depends only on $Q^4 m^{-4}$ (charge and mass of the charged particle) and on spin, $c_{1,s}$ depends on the spin of the particle This leads to ζ_1 of the order of 10^{-14}-10^{-13}

Motivations to look for quartic $\gamma\gamma$ anomalous couplings

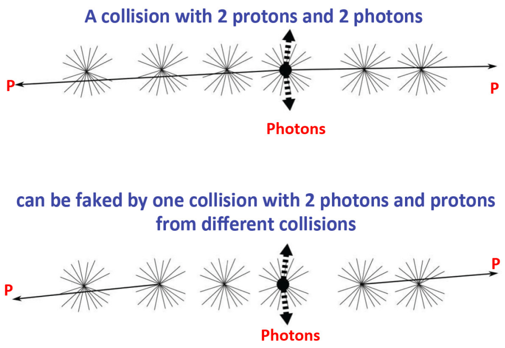


- Two effective operators at low energies

$$\mathcal{L}_{4\gamma} = \zeta_1^{\gamma} F_{\mu\nu} F^{\mu\nu} F_{\rho\sigma} F^{\rho\sigma} + \zeta_2^{\gamma} F_{\mu\nu} F^{\nu\rho} F_{\rho\lambda} F^{\lambda\mu}$$

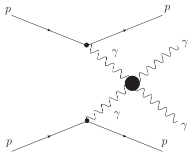
- ζ_1 can also be modified by neutral particles at tree level (extensions of the SM including scalar, pseudo-scalar, and spin-2 resonances that couple to the photon) $\zeta_1 = (f_s m)^{-2} d_{1,s}$ where f_s is the $\gamma\gamma X$ coupling of the new particle to the photon, and $d_{1,s}$ depends on the spin of the particle; for instance, 2 TeV dilatons lead to $\zeta_1 \sim 10^{-13}$

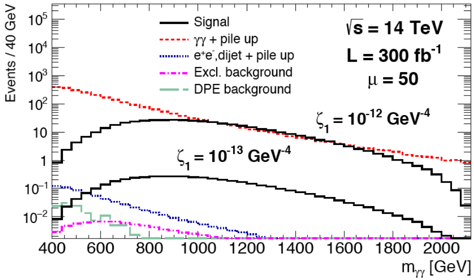
One aside: what is pile up at LHC?



- The LHC machine collides packets of protons
- Due to high number of protons in one packet, there can be more than one interaction between two protons when the two packets collide
- Typically up to 50 pile up events

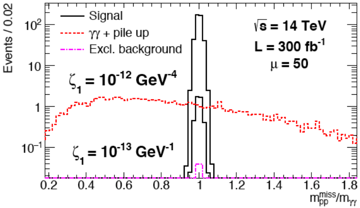
Search for quartic $\gamma\gamma$ anomalous couplings

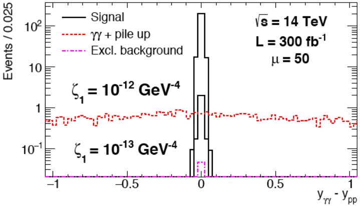




- Search for $\gamma\gamma\gamma\gamma$ quartic anomalous couplings
- Couplings predicted by extra-dim, composite Higgs models
- Analysis performed at hadron level including detector efficiencies, resolution effects, pile-up...
- Anomalous coupling events appear at high di-photon masses
- S. Fichet, G. von Gersdorff, B. Lenzi, C.R., M. Saimpert ,JHEP 1502 (2015) 165

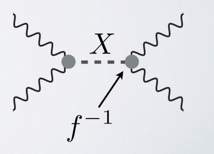
Search for quartic $\gamma\gamma$ anomalous couplings

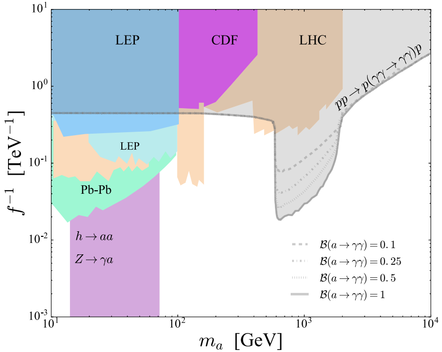




Cut / Process	Signal (full)	Signal with (without) f.f (EFT)	Excl.	DPE	DY, di-jet + pile up	$\gamma\gamma$ + pile up
$[0.015 < \xi_{1,2} < 0.15$, $p_{T1,(2)} > 200, (100)$ GeV]	65	18 (187)	0.13	0.2	1.6	2968
$m_{\gamma\gamma} > 600$ GeV	64	17 (186)	0.10	0	0.2	1023
$[p_{T2}/p_{T1} > 0.95$, $\lvert\Delta\phi\rvert > \pi - 0.01]$	64	17 (186)	0.10	0	0	80.2
$\sqrt{\xi_1\xi_2 s} = m_{\gamma\gamma} \pm 3\%$	61	16 (175)	0.09	0	0	2.8
$\lvert y_{\gamma\gamma} - y_{pp}\rvert < 0.03$	60	12 (169)	0.09	0	0	0

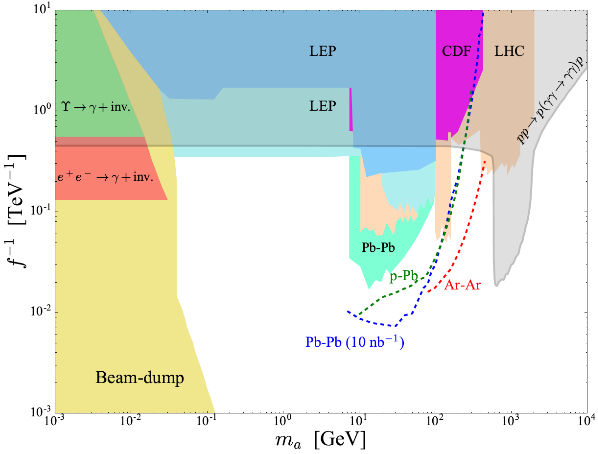
- No background after cuts for 300 fb^{-1}: sensitivity up to a few 10^{-15}, better by 2 orders of magnitude with respect to "standard" methods
- Exclusivity cuts using proton tagging needed to suppress backgrounds (Without exclusivity cuts using CT-PPS: background of 80.2 for 300 fb^{-1})





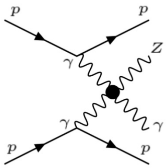
- Production of ALPs via photon exchanges and tagging the intact protons in the final state complementary to the usual search at the LHC (Z decays into 3 photons): sensitivity at high ALP mass, C. Baldenegro, S. Fichet, G. von Gersdorff, C. Royon, ArXiv 1803.10835, JHEP 1806 (2018) 131
- Complementarity with Pb Pb running: sensitivity to low mass diphoton, low luminosity but cross section increased by Z^4

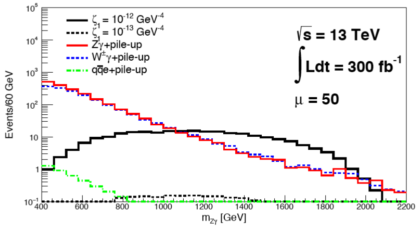
Search for axion like particles: complementarity with heavy ion runs



- Production of ALPs via photon exchanges in heavy ion runs: Complementarity to *pp* running
- Sensitivity to low mass ALPs: low luminosity but cross section increased by Z^4, C. Baldenegro, S. Hassani, C.R., L. Schoeffel, ArXiv:1903.04151
- Similar gain of three orders of magnitude on sensitivity for $\gamma\gamma\gamma Z$ couplings in *pp* collisions: C. Baldenegro, S. Fichet, G. von Gersdorff, C. R., JHEP 1706 (2017) 142

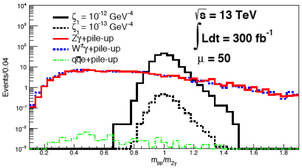
$\gamma\gamma\gamma Z$ quartic anomalous coupling

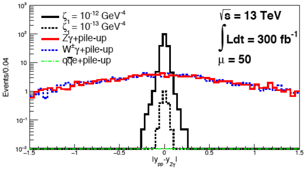




- Look for $Z\gamma$ anomalous production
- Z can decay leptonically or hadronically: the fact that we can control the background using the mass/rapidiy matching technique allows us to look in both channels (very small background)
- Leads to a very good sensitivity to $\gamma\gamma\gamma Z$ couplings

$\gamma\gamma\gamma Z$ quartic anomalous coupling

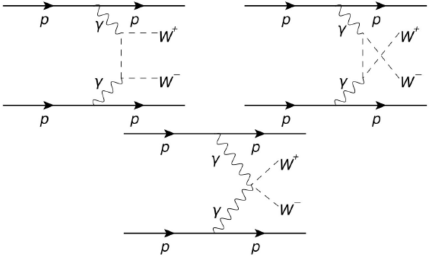




Coupling (GeV^{-4})	ζ ($\tilde{\zeta}=0$)		$\zeta = \tilde{\zeta}$	
Luminosity	300 fb^{-1}		300 fb^{-1}	
Pile-up (μ)	50		50	
Channels	5 σ	95% CL	5 σ	95% CL
$\ell\bar{\ell}\gamma$	$2.8 \cdot 10^{-13}$	$1.8 \cdot 10^{-13}$	$2.5 \cdot 10^{-13}$	$1.5 \cdot 10^{-13}$
$jj\gamma$	$2.3 \cdot 10^{-13}$	$1.5 \cdot 10^{-13}$	$2 \cdot 10^{-13}$	$1.3 \cdot 10^{-13}$
$jj\gamma \bigoplus \ell\bar{\ell}\gamma$	$1.93 \cdot 10^{-13}$	$1.2 \cdot 10^{-13}$	$1.7 \cdot 10^{-13}$	$1 \cdot 10^{-13}$

- C. Baldenegro, S. Fichet, G. von Gersdorff, C. Royon, JHEP 1706 (2017) 142
- Best expected reach at the LHC by about three orders of magnitude
- Advantage of this method: sensitivity to anomalous couplings in a model independent way: can be due to wide/narrow resonances, loops of new particles as a threshold effect

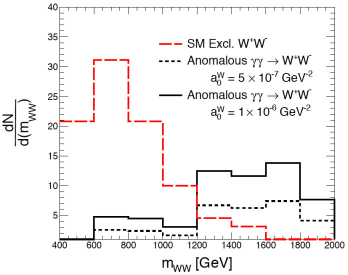
SM observation and anomalous couplings studies in WW events

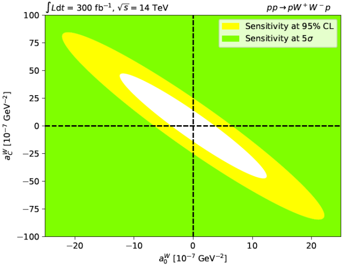


- Possible observation of WW exclusive production at high mass: study all decay channels, 2 "fat" jets, 1 lepton + 1 "fat" jet, 2 leptons

- The SM prediction on exclusive events after selection when Ws decay leptonically: 47 events for 300 fb^{-1} for 2 background events
- 1st possible observation of exclusive WW at high mass with data after shutdown with present configuration: important to check detector acceptance, efficiency, alignment...
- Production of WW anomalous events: Look in hadronic channel at high mass

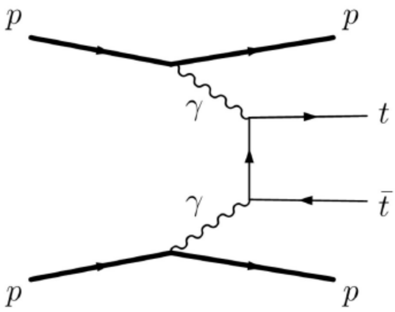
Anomalous couplings studies in *WW* events





- Same method as before: looking for anomalous *WW* production
- Events appear at high *WW* mass, and benefit from mass/rapidity matching to reject background
- Sensitivity down to 3.7 10^{-7} GeV^{-2} (present limits using exclusive production of *WW* at medium luminosity (low pile up) without proton tagging led to limits of $\sim 10^{-4}$ GeV^{-2})
- C. Baldenegro, G. Biagi, G. Legras, C.R., arXiv:2009.08331, accepted in JHEP

Exclusive $t\bar{t}$ production



- Exclusive production of $t\bar{t}$ events: SM observation and sensitivity to anomalous couplings
- SM cross section quite low $\sim$1 fb
- Few events might be observed with 300 fb^{-1}, and higher statistics available at high lumi LHC (3000 fb^{-1})
- Studies in progress including background with A. Bellora, M. Pitt, C. Baldenegro, S. Fichet, G. von Gersdorff, C.R.

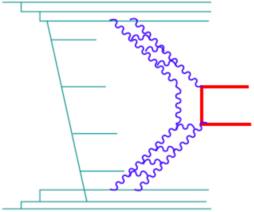
Conclusion

- Discovery of the odderon, the t-channel exchange of a colorless C-odd gluonic compound by comparing D0 $p\bar{p}$ and TOTEM pp elastic data: FERMILAB-PUB-20-568-E; CERN-EP-2020-236 submitted yesterday to PRL!
- Better understanding of pomeron exchange in terms of quark and gluon structure at the LHC: dijets, γ+jet, WW...
- LHC can be seen as a $\gamma\gamma$ collider!
- $\gamma\gamma\gamma\gamma$, $\gamma\gamma ZZ$, $\gamma\gamma WW$, $\gamma\gamma\gamma Z$ anomalous coupling studies and SM observation $\rightarrow$ "Background-free" experiment and any observed event is signal

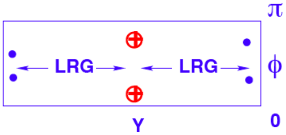
We need to look everywhere! For instance using intact protons...

Hard diffraction at the LHC: A difficulty to go from HERA to LHC, Survival probablity

- Use parton densities measured at HERA to predict diffractive cross section at the LHC
- Factorisation is not expected to hold: soft gluon exchanges in initial/final states
- Survival probability: Probability that there is no soft additional interaction, that the diffractive event is kept
- Value of survival probability assumed in these studies: 0.1 at Tevatron (measured), 0.03 at LHC (extrapolated)

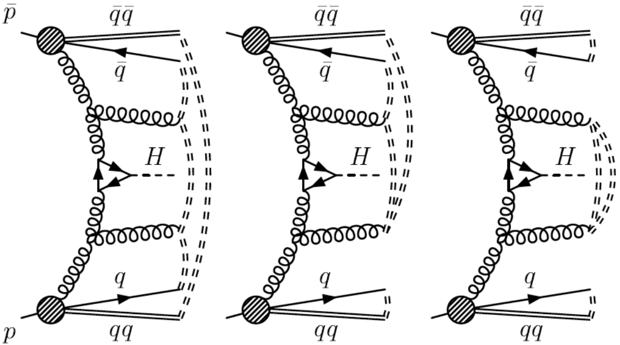


a)

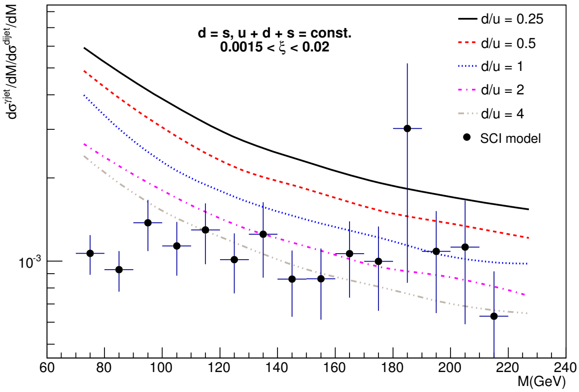


b)

Soft Colour Interaction models



- A completely different model to explain diffractive events: Soft Colour Interaction (R.Enberg, G.Ingelman, N.Timneanu, hep-ph/0106246)
- Principle: Variation of colour string topologies, giving a unified description of final states for diffractive and non-diffractive events
- No survival probability for SCI models

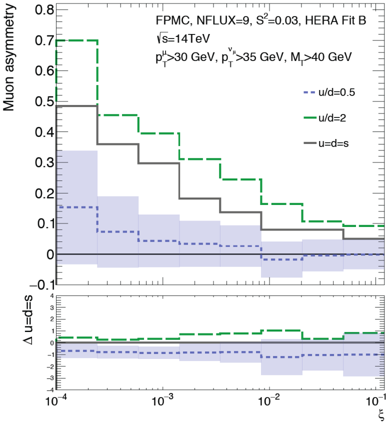


- Predict DPE γ+jet divided by dijet cross section at the LHC for pomeron like and SCI models
- In particular, the diffractive mass distribution (the measurement with lowest systematics) allows to distinguish between the two sets of models: flat distribution for SCI

The Forward Physics Monte Carlo (FPMC)

- FPMC (Forward Physics Monte Carlo): implementation of all diffractive/photon induced processes
- List of processes
  - single diffraction
  - double pomeron exchange
  - central exclusive production
  - photon induced processes (and anomalous couplings)
- Inclusive diffraction: Use of diffractive PDFs measured at HERA, with a survival probability of 0.03 applied for LHC
- FPMC manual (see M. Boonekamp, A. Dechambre, O. Kepka, V. Juranek, C. Royon, R. Staszewski, M. Rangel, ArXiv:1102.2531)
- Output of FPMC generator interfaced with fast simulation of ATLAS/CMS detectors

W asymmetry: sensitivity to quark densities



- Measure the average W charge asymmetry in ξ bins to probe the quark content of the proton: $A = (N_{W^+} - N_{W^-})/(N_{W^+} + N_{W^-})$
- Test if u/d is equal to 0.5, 1 or 2 as an example
- A. Chuinard, C. R.,R. Staszewski, JHEP 1604 (2016) 092